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Multi Hazard scenarios in the Mendoza/San Juan provinces, Cuyo Region Argentina

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Abstract

This paper exposes major natural hazards inventory encountered in the two San Juan and Mendoza provinces, such as climatic, seismic, gravitational, and social/anthropic ones. The contrast between the high altitude of the region and low one is addressed in order to manage the inhomogeneity of prevention plans. The international road to Chile is greatly affected by gravitational hazards that proceed in out of run period and commercial traffic interruption, and large economic waste more than people vulnerability, as the urban areas are more affected by seismicity scenarios. But as gravitational hazard is affected by the seismicity it is proposed to analyze some co-hazard effect in a multi-scenarios approach from geology geography and mechanical modelling of events to explore the co-effects on the scenarios. Moreover, some similarities with the Rhone-Alpes region of France are evoked and may be of interest.

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Keywords: hazard inventory; Cuyo Region Argentina; multi scenarios; interdisciplinarity

1. Introduction

The provinces of Mendoza and San Juan, in the Cuyo region (Argentina) are situated at the foot of the highest part of the Central Andes. This semi-arid region characterised by large concentrated urban areas such as Mendoza and

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San Juan capital cities (800000 and 120000 inhabitants respectively). They were founded in the 16th century (Correa 2008) being affected by various destructive seismic events. This part of the world, near Chile, is one of the most seismic regions and it is also greatly susceptible to climate hazard in highest altitude areas. Aconcagua Mount reaches 6958 masl, while permafrost stays over 3,800 masl. Region climate is affected by both Atlantic and Pacific Anticyclones leading to perturbations with contrasted precipitations. The region has great economic reliability through tourism, agriculture and wine production. Economical exchanges with Chile exist through the international road to Santiago de Chile that also connects with Buenos Aires and Brazil, reason why this road is known as Bioceanic corridor. Today, the infrastructure uses a tunnel at 3,200m (Las Cuevas), but for a long time a 3,850 m frontier pass was the only crossing point. In fact, around 80% of the terrestrial heavy trucks traffic for commercial exchanges cross the Andean mountains by this road. A large project of a second bi-oceanic corridor is through the 4,700 m Agua Negra Pass at east of San Juan city is of actuality and will need quite the same civil engineering infrastructures as road 7 one's (tunnels, bridges, protections, dams). As the areas are affected by large storms, windy and snowy conditions, the highways may be out of run several days due to large gravitational flows, rocks falls, and snow avalanches. In period of developing hazard plan and resilience considering, this context raises some potential investigations and methods that should be done in order to understand and quantify the phenomena and the specific related questions from a scientific point of view, and evaluate the variability of the scenarios. The aim of this paper is to generate an inventory of multi natural hazards as suggested by Wick (2010) for the ruta 7, in order to suggest preventive measures on this key infrastructure. The Rhone Alpes region and Grenoble city is one the most active seismic zone of France, and some similarities in the geography may allow comparison of interest and rich in an interdisciplinary and inter regionally companion work. Indeed, the region has several large urban areas, high mountains and cross-border infrastructures well used such as Lautaret/Mongenevre itinerary to Italy, Mont-Blanc/Modane tunnels. The paper presents first some natural hazards of the Mendoza province, then the evidence of multi-hazard scenario is deduced and mitigation measures are proposed. A parallel with the Rhone-Alpes region is presented. As conclusion, some prior possibilities of works are proposed in an engineering point of view.

2. Natural Hazard Inventory of Mendoza Province

2.1. Seismic hazard

The Cuyo region is the most seismic zone of Argentina, still reported events start in the 16em century (INPRES 1985). Large catastrophic events occurred in the last century leading to the destruction/reconstruction of the cities of San Juan and Mendoza. Events with magnitudes between 4 and 5 regularly occur: in 2013, 58 events were reported in San Juan (weekly frequency), whereas a monthly frequency is observed in Mendoza (Figure 1).

The seismicity in the region is due to both active local faults and to Chilean subduction like the last Iquique event in April 2014. In the Mendoza piedmont region, active faults cross the urban areas of the capital, (Moreiras and Páez, 2014). The same situation exists in San Juan city (see faults map fig 1d). These active faults generate most of the seismicity of the two provinces. Even further Chilean subduction earthquakes are generally registered. Due to this high hazard, the seismic studies institutes of Argentina (INPRES-created after the destruction of San Juan in 1944, IDIA, IMERIS, CEREDTEC, CCT-CONICET) involved in the risk evaluation are localized in this region, managing and reporting accelerometers net measurements. For building codes design, INPRES defined the Argentina zoning with 4 levels, giving the highest values (4) to all the Mendoza and San Juan province's territories, without considering any local amplification factor except in some particular zones where the ground accelerations were defined more precisely (Tonnelo 2010).

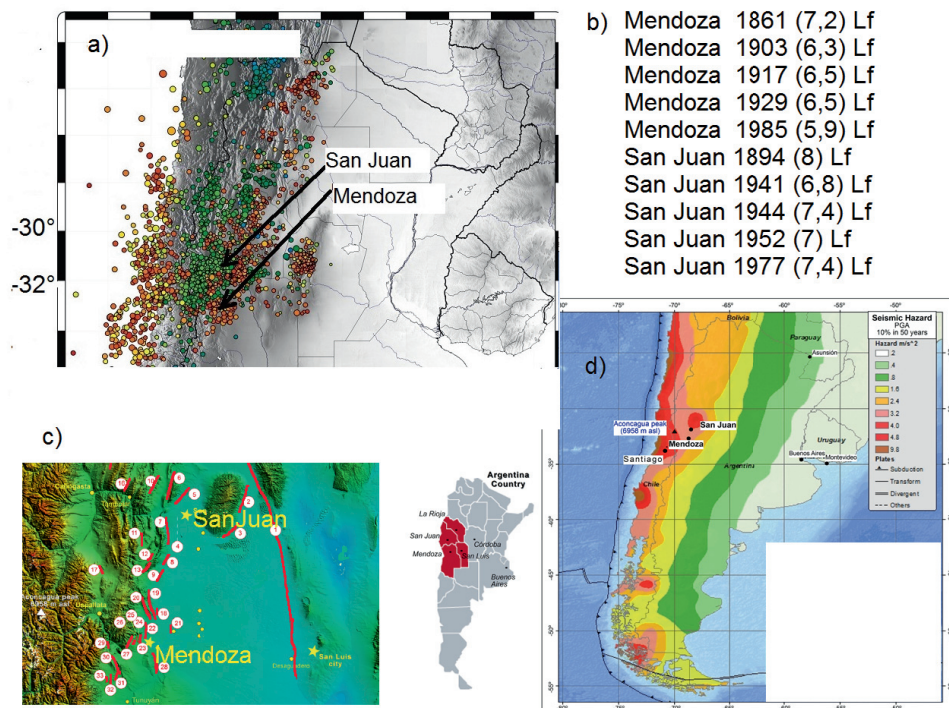


Fig 1: (a)-seismicity map of Cuyo region (INPRES) and (b)-catastrophic historical events with liquefaction (Lf) (Moreiras 2004) (c) active faults at the piedmont of the central Argentinian Andes (Moreira 2014). (d) Potential ground motion for Argentinean local and subduction Chilean earthquakes in Moreiras (2014 from USGS)

2.2. Geological considerations

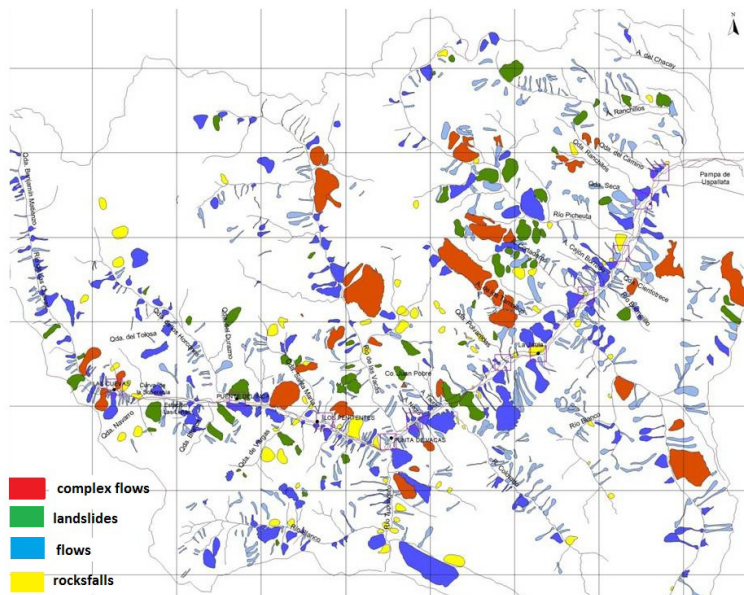
The liquefaction phenomena is a well-known behavior of saturated soils especially under dynamic loading and part of the damage in urban areas as it is a triggering factor of soil failure (Youd 1978). The dynamic over-pressure on the liquid phase of the saturated soil leads to a liquid like behavior instead of solid one. The liquefaction soils susceptibility may be measured by cone penetration test and is generally common in the sandy and Limon soils (Robertson 1992). The alluvial terrains of great part of the Mendoza/San Juan provinces is constituted of silty and sandy soils that are the soils type with a high susceptibility of liquefaction. The evidence of liquefaction effects in the region for the historical earthquakes has been documented (Perucca and Moreiras, 2006, Moreiras and Páez, 2014) especially in Holocene sediments with upper phreatic levels. Some areas demonstrate to be prone to liquefaction when adequate geotechnical tests are done. These areas were identified, as demonstrating seismic liquefaction “secondary effect” hazard precursors and a micro-zoning was defined, in coincidence with the all urban sites of Gran Mendoza and San Juan (INPRES 82)).

2.3. Climatic hazards

Various contrasted climatic effects affect the Cuyo region as it considers semi-arid latitudes (29°S to 34°S) with large altitude range (500 m to nearly 7000m). Topography forces precipitation being less than 100mm/year in the lowlands to more than 500mm/year in the highlands. Region is affected by both Pacific and Atlantic oceans perturbations. The influence of latter are limited to the western Cordon del Plata range, 1200 km from Atlantic coast. Whereas the Pacific influence could not really cross the highest cordilleran summits being associated to snow precipitations in high altitude during winter season; while the Atlantic Anticyclone leads heavy summer

High altitude frozen zones over 4000 to 4500 m are generally in icy conditions all over the year but less altitude ones thaw within the day/night and summer/winter temperature cycles.

Gravitational hazard in the highest part is concerned by winter snow avalanches, gravitational soils and rocks, low and rapid movements communally occur affecting the road 7. The historical landslides have been reported in figure 2 and classified (Moreiras, 2004) in order to develop a hazard map. Rockfalls are more frequent in steeper rock slopes while debris-flows are associated to huge basin. Latter are the most frequent event, and could reach more than 1000 m track (Moreiras 2006; 2008), affecting infrastructures (road 7 and the trans-andine railway, out of run since 30 years but nowadays in mind again as an alternative possibility of heavy traffic). Damaging debris flows were reported in 2013 (Moreiras and Sepulveda, 2013; Sepulveda et al., 2014). Moreover, many of this gravitational movement are inactive but may be reactivated.



A relative low precipitation threshold value between 6 to 12 mm estimated for rockfalls and debrisflows (Moreiras 2008) went though a lack on mountain meteorological station. Seismic relation with mass movement is also of evidence as provided by Keefer Magnitude/epicenter distance threshold pioneer relation. As coming from incomplete data analysis it depicts that a co-seismic triggering may start from $M > 4$ to $M > 6$ depending of the epicenter distance. Rockfall along the Mendoza river valley have been triggered by $M_{s3.9}$ earthquakes. However no good correlation exist between magnitude of earthquake and volume of collapsed material, neither between magnitude of earthquake and distant of epicenter. Earthquake with distant epicenter have triggered rockfalls, Maule

earthquake in February 2010 (Ms 8.2) with epicenter 300 km far from the area generated many rockfalls in Aconcagua Park (Wick et al, 2010). As demonstrated by Burjanek J.(2011) less value has been recorded presenting that ground motion (taking into account the local amplification effect) is a more pertinent parameter and that amplification factor may be used if necessary.

Gravitational events have great influence on the economic development as (, when occurring, the road may be cut for several days and international traffic stopped up to the complete restoration of the infrastructures. The economic wastes are directly related to the duration of the out of run.

2.5. Social components

The Cuyo region is characterized by contrasted areas: densely populated zones around the cities of Mendoza and San Juan and empty mountainous areas. In the urbanized areas, both San Juan and Mendoza cities were completely destroyed by historical great seismic events. As demonstrated in flood risk perception by (Viggilione 2014) , the collective memory may largely be involved in the perception and preparation of the population to catastrophic events.. In the investigated area, the return period of major earthquakes is quite long as the Cauçete event (Magnitude 7.4) occurred in 1977. The complete generation of adults (up to 35 years) does not have any experience of strong earthquake, even if training exercises are done at school, at work... and even if the 2010 Chilean event was felt in both provinces. An ongoing perception survey in Mendoza ciudad (collaboration between Univ. of Grenoble and Univ. of Cuyo, Mendoza) may help considering if the knowledge of safety measures as well as seismic risk perception and preparedness strategies are different for several social groups defined by age, gender, study level, earthquake experience, etc. This may also help emphasizing resilience factors of the population facing several natural hazards.

If the Mendoza and San Juan gather 2,420,000 inhabitants (INDEC, Censo 2010), the population is concentrated in urban areas, where human, economic and physical vulnerabilities are greater due to the concentration of buildings, population and activities. In mountainous context, vulnerabilities are different: the probability of deaths is lower due to low densities. The vulnerabilities are more related to networks. First, the economic activities that depend on these roads are most vulnerable. The traffic interruption could generate millions of dollars loss. Secondly, mountainous populations may be isolated during several days: because they do have to face the same threat, their resilience factors are certainly different from urban populations. Special attention could also be given to tourists who are numerous in the studied area region (wine tourism, andinism...). They are a priori less familiar to hazards they are exposed to, what increase their vulnerability (Kelman et al., 2008). The exposure is also different between urban and mountainous populations, due to distinct hazards they have to face (see paragraphs above).

3. Evidence of co-seismic co-rainfall co-social scenarios

Here we have to point out that cities are located out of the mountain environment, then collapse or gravitational processes will affect communication systems (like international road to Chile). However, cities could be affected by other secondary seismic events like liquefaction or local ground acceleration due to soil material (measured by UTN). San Juan airport is situated on soils prone to liquefaction and the high seismic province deals with the same hazard inventories as geographically similar. Climate hazards could affect both mountain environment and lowland cities. The analysis of natural hazards of the Cuyo province is quite complex as for vulnerability and risk management, the contrast between urban and non-urban areas constitutes a difficulty to homogenize the scenarios and methodology. In fact, not only the human vulnerability should be studied but the economic and social ones. Depending on epicenter distance the minimum magnitude to trigger rock falls may start between 4 and 5 (Keefer 1984, 1988, 2002, Moreira 2006), and amplification factors due to topography, geology is necessary to be known especially in the possible fracturing of recurrent seismicity without apparent damage as co-seismic triggering in critical spots is possible.. The inventory of past gravitational events gives a good mapping of potential event localization, but may not be exclusively relevant of future events. Occurrence conditions are not well known due to lack of observation and observers. Some numerical simulation of return analysis may help (Taboada 2007, Cuervos 2013) to explore the potential threshold parameters the consequence of variability (Baroth 2012). As experimental studies is hard work (Manzella 2013) and but had permitted calibration and validation of the numerical modelling of

rock avalanches (Richefeu 2012) Relevant numerical results run out, flow velocities, “Fachboschung angle” may be compared with classical ones and proposed to evaluate the vulnerability of peoples, infrastructures the increase of expertise on a typical case is of interest, and the effect the initial mechanical energy, given by the dynamic seismic ground loading is not actually considered in the deposit run-out on co-seismic event, nor the fracturing effect of initial volume due to M4-5 ground motions. Moreover Moreiras depicted that largely high fractured/degraded zone combined with co-rainfall seems to generate debris flows as .Those rapid events have greater technical and economic impact and generate more vulnerability than slow one (Mora 2010). Smaller solicitation effects such as wind and heavy traffic waves could be also computed if some sites topographic amplification effects are evident.

Seismicity is also of importance for urban areas as the destruction of the city’s infrastructure is a key factor in the risk management, and it has been demonstrated that large zone are in liquefaction potential areas (Moreiras 2007). The post seismic analysis of Christchurch (New Zealand) damaged areas conduced to abandon some large areas due to liquefaction susceptibility (Cubrinovski 2012) that is of importance in the urbanization future plans managing of every cities. Analyzing the multi hazard scenario Wasowski (2011) suggested studying co-rainfall and co-seismic hazard as dynamic loading generate liquefaction phenomena initiating some gravitational events.

The climate change may modify the frozen zones altitude, in higher it and displacing the pacific-oceanic influence border himself as well as the snow/rainfall limit. The hazard in the mountains area will change by increasing numbers of events and decrease the return frequency. This will modify the actual zoning as small return frequency with better reliability due to collective memory and generally less intensity that allows possible efficient protections.

Conclusion

Mendoza and San Juan Provinces are territories of contrast due to high and low altitude, semi- arid climate, permafrost melting, isolated and urban areas...Regarding the checklist of the potential hazard, it is observe that many of them could interacts and a multisenarios should be proposed. Hard constraints of the zone lead to sometimes contradictory and/or additional and/or successive problematic for the urban and non-urban areas that complexify hazard managing due to inhomogeneity. It may be possible to propose methodology to divide in homogenous zone. Moreover developing hazard plans and trying to evocate resilience, the discussion raises some investigations potential subjects and methods that should be done in order to understand and quantify the phenomena and the specific related questions from a scientific point of view, and evaluate the variability of the scenarios. As both territories may be in altitude disparities, a comparison with the Rhone Alpes region may done keeping in mind an evident scale factor especially in altitude characteristics. The same contrasted constraints are facts for this similarity: few inhabited Alpes mountains and large urban lowlands and cities, economic reliability in outdoor tourism, agriculture zone, and heavy traffic infrastructure with exposed critical point between Italy and France And several process such as the debris flows, avalanche, rockfalls, and as recently, the 7 April 2014 seismic events of M5.

It also necessary to identify probable chain reactions against which authorities may be destitute, as these reactions are rarely taken into account in emergency plans.

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- CEREDETEC <http://www1.frm.utn.edu.ar/ceredetec/> Centro Regional para el Desarrollo Tecnológico de la Construcción, Sismología e Ingeniería Antisísmica [CeReDeTeC]
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